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Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

December 1957

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SUBURBAN SEWAGE TREATMENT BY THE ANAEROBIC CONTACT PROCESS

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(December, 1957)

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Public Health Service
U. S. Department of Health, Education, and Welfare
Cincinnati, Ohio

A need for workable means of suburban sewage treatment has been growing throughout the United States. It is most acute in isolated suburbs with poor soil absorption characteristics.

A scheme of sewage disposal that has great practical merit is the subdivision sewer system connected to a small treatment plant. The planned location of these small treatment plants in a drainage basin makes integration into a large sanitary district possible. Trunk sewers can be constructed later connecting the subdivision sewer system, eliminating the smaller interim plants in favor of one large treatment plant. The cost of suburban sewer systems and small plants installed during the construction of a housing project has been shown to be often less than individual disposal units(1). This suburban system will increase the value of the property and decrease the health hazards of waste disposal in areas unfit for individual units.

The acceptability of a scheme of suburban sewers and plant lies in the suitability of the small sewage treatment plant selected. A disposal plant must be judged on the quality of effluent it produces(2). However, from the practical viewpoint, the suitability of a small disposal plant depends upon the economics of producing an effluent quality that will protect the health and property of the people in the area.

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The treatment facilities should be low in original cost, and operational cost must be kept small by designing the plant to require little maintenance. The first cost of this system of sewers and small plants must be justifiable to the builder. The increase in property value, the absence of land requirement for individual disposal fields, the ability to obtain Federal loan insurance, and the initial cost of this system must be economically favorable over the individual disposal units. Maintenance costs must be held to the normal monthly 1 to 4 dollars per connection sewer charge. In essence, this means weekly or monthly maintenance.

Previous Laboratory Studies

In a laboratory bench-scale study, a long detention in an anaerobic sludge contact tank followed by an upflow rock column gave promising performance(3). This unit removed 67 percent of the BOD (Biochemical Oxygen Demand) under cold weather conditions and 81 percent under warm weather conditions, and gave high suspended solids removal, above 90 percent under both conditions. Since the process required no moving equipment and little maintenance, it promised exceptionally low original and maintenance cost.

General Description of the Anaerobic Contact Process Pilot Plant

Following the encouraging laboratory investigation, an anaerobic contact process pilot plant was initiated at Loveland, Ohio, on the grounds of the village sewage treatment plant. This study has now been in operation for over a year, and the effects of a yearly temperature cycle have been observed.

The pilot plant receives domestic sewage from the influent line of the existing primary clarifier. Raw sewage is first brought into contact with the sludge zone in the bottom of the first tank and flows upward to an outlet at the top of the tank. The effluent from this unit then flows upward through a submerged rock column and discharges back into the village treatment plant. Both units used in the process are operated under anaerobic conditions.

Figure 1 shows a cutaway of the pilot plant. The primary tank is conical in shape, and has an 18-hour detention. The secondary tank is a 4' x 4' x 7' column, and has a 6-hour detention. The flow is 1.15 gal/min; its direction is shown by the arrows on the figure. Samples were taken in such a manner that each of the two units could be evaluated as a separate process. Analysis of accumulated data has led the authors to discuss these units separately.

The Sludge Contact Unit

The primary unit was designed to incorporate the anaerobic sludge contact principle which has been successfully used in treating industrial waste(4). Raw sewage is introduced at the bottom of the tank and immediately comes into contact with the blanket of digesting sludge. The incoming sewage flowing upward through the sludge zone mixes with the digesting sludge, and a large percentage of the fresh solids are removed. The clear liquid volume above the sludge zone provides time for resettling of the fine sludge particles carried from the blanket by sudden increases in the flow.

The conical tank, as seen in Figure 1, has a capacity of 1240 gallons and the slope of the side is 60° with the horizon. The outlet is protected by a scum baffle. Automatic sampling valves on both the influent and effluent lines released samples every half hour which were composited in appropriate containers. Precautions were taken to prevent gas leaks and the entrance of atmospheric air. All gases generated in the tank must either escape from the tank through the wet test meter or be dissolved in the liquid effluent.

Suspended Solids, COD, and BOD Removals

The sewage entering the pilot plant showed suspended solids and BOD strengths typical of a domestic source. Figure 2 shows the daily fluctuation of COD (Chemical Oxygen Demand) and suspended solids strength. These curves represent the average of data obtained from hourly samples taken over a 24-hour period on three separate days. The standard 5-day BOD test and the COD test using $AgSO_4$ catalyst were made on daily composites for the first 7 weeks. The relationship between BOD and COD for Loveland sewage was found to be BOD(ppm) = 0.38 COD(ppm) - 20. For the balance of the year the convenient COD test was used on daily composites, and the BOD was run on one sample a week as a check on the BOD-COD relationship. These checks did not reveal any significant change.

In Table 1, average suspended solids, COD, and sulfides are given for the sludge contact tank. The table has been divided into a break-in period (weeks 0-15), a cold-weather period (weeks 16-36),

and a warm-weather period (weeks 37-52). Average removal over the year was 83 percent suspended solids and 62 percent COD. The primary effluent was inoffensive in odor with an average of 2.8 ppm of sulfide. Removals of both COD and suspended solids varied with temperature. During the warm seasons of the year, removals were greater than those obtained during winter operations. From November to March, when the mean air temperature was below 3.5°C, the primary unit removal averaged 54 percent of COD and 74 percent of suspended solids. From April to July, in which the mean air temperature was 19.7°C, average removals of 77 percent COD and 88 percent suspended solids were obtained.

TABLE 1 - SLUDGE CONTACT TANK

Months	Weeks	Suspended Solids			COD			Sulfides	
		Inf	Eff	% Removal	Inf	Eff	% Removal	Inf	Eff
July-Oct	0-15	333	66	80	697	327	53	1.5	6.2
Nov-March	16-36	286	73	74	634	293	54	0.9	1.8
Apr-July	37-52	671	77	88	743	171	77	0.1	1.8
July-July	0-52	429	72	83	695	263	62	0.6	2.8

Figure 3 is a tabulation of the weekly averages of the determination made on daily samples from the pilot plant. Figures 4 and 5 show graphically the operational data tabulated in Figure 3. These curves present the magnitudes of COD and the suspended solids of the effluents, and give the magnitude and variations of removals

with time in the sludge contact tank. The figures show the variation of efficiency with temperature. Both suspended solids and COD removals increased after the temperature rose above 10°C.

Gas Production

All gas produced in the tank must either leave through the gas meter or be dissolved in the effluent. A daily record of gas passing through the meter was kept and on several occasions analyses were made of the effluent. During the year, only 600 cu. ft. passed through the meter. Gas analysis demonstrated little or no methane (CH_4) and negligible carbon dioxide (CO_2). On two occasions effluent samples were stripped of dissolved gases by scrubbing with CO_2. Analysis of the resulting mixture of CO_2 and the gases stripped from the solution failed to demonstrate any measurable CH_4.

Sludge and Scum Accumulation

There was an absence of scum formation in the sludge contact tank as is present in other anaerobic systems, such as the Imhoff tank and septic tank. The presence of spring and summer temperatures did not produce an upset as is common in other anaerobic systems, caused by the violent spring gas production with resulting solids dispersion through the tank liquid.

The sludge in the contact tank, because of its importance in the method of treatment, has been studied in detail. Because the laboratory study was begun with the use of seed sludge, it was decided to determine if the unit would function initially without the use of seed sludge. The sludge contact unit started with a 45 percent removal

of COD and an 80 percent removal of suspended solids. During the first 9 weeks of operation a sludge accumulation of 13 cu. ft. took place and was accompanied by a gradual increase in efficiency, raising removals to 60 percent COD and 87 percent suspended solids. It was concluded that the unit had been successfully put into operation without the use of seed sludge. In order to accelerate accumulation and determine performance at a higher sludge level, 200 gallons of digested sludge were added during the 10th week. The added sludge contained 192 pounds of total solids with a volatile content of 37.6 percent.

Suspended solids tests show that during the year, 1780 pounds dry weight of solids were entrapped in the first tank; however, at the end of the period the tank had 65 cu. ft. of sludge with a total dry solids content of 305 pounds with a volatile content of 60 percent. Measured gas production does not balance the amount of solids lost. An explanation of the small gas production has not yet been found.

It was originally felt that the sludge blanket would act as a combination of surface contact and distribution media. Model studies as well as pilot plant observation showed this not to be entirely true. The sludge particles tend to jell into a mass, and the incoming flow forms channels through the blanket. When sudden large increases in flow occur, the sludge blanket does not expand evenly. Rather, channels in the blanket are enlarged or changed and solids are carried into the liquid volume above the sludge zone. However, expansion of the blanket does occur when the flow is held constant at the increased velocity.

The sludge settling velocity is an important design parameter which is needed to determine the cross-sectional area in the upflow basin. Several models were constructed to determine at what flow the sludge would be held in suspension, but not be washed out of the tank. Because of the large range of sludge particle sizes, some solids were washed out at all tested flow, even down to velocities of less than 2 ft/day. Increases in flow wash out more solids at the beginning of the increase than in subsequent periods of sustained increased flow. Pilot plant operations substantiated these observations.

It was observed that below the upflow velocity of 15 ft/day, the sludge zone had a definite line of demarcation, but above that rate the sludge zone was less distinct and increase in the solids content of the effluent occurred. Several models and pilot plant studies have given this flow velocity figure. Model studies have dramatically shown sludge zone demarcation, and shock loading of the pilot plant has shown severe solid content increase in the effluent when upflow velocities of greater than 15 ft/day were applied.

Hydraulic Characteristics

Detention times and hydraulic characteristics of the primary tank have been studied in both the pilot plant and in various models. The theoretical detention time is 18 hours, which is based on the assumption of an orderly upward displacement of the liquid. The difference in temperature between tank liquor and incoming sewage, the sludge volume, and the shape of the tank all affect the flow pattern and the detention time.

The density difference, when the temperature of the incoming raw sewage is warmer than the liquor in the tank, causes a short circuiting. This is the typical case; when the tank liquor has cooled, warmer incoming sewage quickly rises to the surface, causing a noticeable decrease in the modal detention of a dye tracer. However, when the raw sewage is cooler than the tank liquor, the density difference promotes an orderly upward displacement.

The increasing volume of the sludge continually decreased the displacement volume of the conical tank. The sludge zone assumed over one-third of the volume of the tank in a year. The volume of the sludge particles substantially decreased the liquid volume.

The sludge contact tank was given a conical shape for reasons of flow distribution, and for the testing of sludge settling velocity. However, model studies conducted on comparisons of flow characteristics between a conical and cylindrical shape tank show the expanding cross-section of the cone to be of no benefit in the distribution of flow.

The first studies were a series of the detention time of slugs of tracers in the pilot plant. Both fluorescein dye and radioactive tracers were used at different temperatures and flow rates. The results showed that shortcircuiting was occurring, and that its magnitude varied with temperature. The liquid temperature in the pilot plant tanks, which are located above ground, varied directly with the air temperature. Thus, the air temperature indirectly caused large changes in the detention characteristic of the flow.

An example of the detention of an instantaneous dosage of dye tracer in the pilot plant's primary tank is shown in Figure 6. This curve shows the modal detention to be 3 hours, and the median detention to be 5 hours. First traces were seen in the effluent in 1½ hours and last traces in 20 hours. The tracer used in this study was put in the primary tank when that tank was 1/3 full of sludge, with an average air temperature of 23°C, and a flow of 1.55 gpm.

TABLE 2

DYE TRACER STUDY RESULTS

I	II	III	IV	V	VI	VII	VIII	IX
Date	Air Temp °C	Theoretical Detention* Hours	Modal Dye Detention Hours	Efficiency $\left(\frac{IV}{III} 100\right)$ %	"N" $\left(\frac{VIII}{VIII-IV}\right)$	Sludge Zone Volume Ft^3	Median Detention Hours	Efficiency $\left(\frac{VIII}{III} 100\right)$ %
9-5-57	29.5	18.	8.0	44	3.9	7.4	10.8	60
10-8-56	20.5	19.	5.0	26	2.0	23.5	10.0	53
1-10-57	-2.8	9.	1.0	11	1.2	39.0	5.2	58
2-5-57	1.0	18.	2.5	14	1.3	62.0	9.8	54
7-17-57	23	13.	3.0	23	2.5	72.0	5.0	38

*Theoretical Detention = volume of cone ÷ flow (have disregarded sludge zone volume)

In Table 2, the results of the series of tracer studies are given. It can be seen that short circuiting exists regardless of the temperatures or the sludge volume. However, the severity of short circuiting was increased, as can be seen by the decrease in the modal detention line, as the air temperature decreased. As the air temperature falls below the temperature of the warm incoming sewage, which is relatively constant, the liquid in the tank is cooled. The less dense warm sewage rises quickly to the outlet, causing the decrease in the modal dye detention. The efficiencies in Column V and the "N" values show the increase in short circuiting with decreasing air temperature. Another factor can be noted from this table, the efficiency, based on the median dye detention, decreases as the volume of the sludge zone increases. All data presented are from tests in which virtually all the dye was recovered.

Observations of dye tracer in a model of a cylindrical tank and a conical tank were undertaken to determine the feasibility of the more economical cylindrical shape. The models were of identical height and the maximum cross-sectional area of the cone was equal to that of the cylinders. The slope of the cone was 60° with the horizon, identical to the pilot plant installation. A second cylindrical model was used with the previous cross-section, but with only one-third the height giving a volume equal to that of the cone. Dye detention was greatly affected by thermal density currents in the liquids. Detention of the dye was mainly a function of volume when favorable thermal gradients existed. Height and shape had little effect on the detention;

however, multiple outlets had a beneficial effect by reducing the "dead area" caused by a single outlet. When the unfavorable thermal condition of warmer incoming liquid existed, dye detention was neither a matter of shape or height and volume played a minor part. The thermal density difference was the controlling factor in all models.

The Rock Column Unit

Past experience with other anaerobic processes made it seem probable that the primary unit would be subject to periodic disturbances resulting in loss of solids. For this reason, and because of a desire for additional treatment, an anaerobic rock column was incorporated into the treatment process. The use of a rock media was decided upon to provide surface area for additional treatment and to act as an agitator on any gas laden particles carried from the first unit.

In the laboratory, the rock column was observed to be free from maintenance requirements and to provide additional treatment. Solids removal was evident in the unit. Plugging was shown to be unlikely as the entrapped solids were easily drawn off when the unit was dismantled. In the laboratory the rock column and the sludge contact tank were tested as a combined unit.

The rock column as installed in the pilot plant is shown in Figure 1. The rock medium in this column is 4' in depth and has a 4' x 4' cross-section. The rock is 1½" to 2½" in size and is a

river deposit gravel. There is a 1¼' liquid depth over the rock and 1' height of distributing volume below the rock. The total liquid volume is 410 gallons. Flow from the first unit enters the column at the bottom and flows upward through the rock to a weir outlet at the top which is protected by a scum baffle.

Suspended Solids; COD and BOD Removal

The operational data of the rock column have been collected and analyzed as an individual unit in the pilot plant study. The BOD and COD had the linear relationship expressed earlier. Weekly averages of the daily analysis are tabulated in Figure 3, and shown combined with the sludge contact unit in Figures 4 and 5. Figures 4 and 5 show the contribution of the rock column as a part of the process for disposal. COD and suspended solids strengths vary less in the influent and effluent of the rock column than in the raw sewage. In Figure 5, the rock column shows ability to remove additional solids. This fact is most significant when solids in the primary effluent suddenly increase. In the testing procedure, several major disturbances were caused in the sludge contact unit which resulted in an increased amount of solids in the influent of the rock column. The rock column effectively reduced these solids to a more constant strength level in the final effluent.

TABLE 3 - ROCK COLUMN TANK

Months	Weeks	Suspended Solids			COD			Sulfides	
		Inf	Eff	% Removal	Inf	Eff	% Removal	Inf	Eff
July-Oct	0-15	66	32	51	327	287	12	6.2	14.5
Nov-March	16-36	73	39	47	293	226	23	1.8	8.7
Apr-July	37-52	77	51	34	171	205	- 20	1.8	9.4
July-July	0-52	72	41	43	263	237	10	2.8	10.2

Table 3 gives the average of results for the year and for the three previously defined periods. The yearly average was 10 percent COD removal. The COD removal varied with temperature with a removal of 23 percent in cold weather and a minus 20 percent during warm weather. This decrease of COD removal was accompanied by a large gas production causing an increased carry-out of solids in the effluent.

Suspended solid removal averaged 44 percent in the tank over the year. The removal of suspended solids did not vary as greatly with temperature as did the COD removal. However, suspended solids increased in the effluent during warm weather after rapid gas production started. Table 3 shows a decrease in suspended solid removal from 47 percent during cold weather to 34 percent during warm weather.

The COD and the suspended solids removals were influenced by the production of gas during the warm weather. However, this disturbance could have been eliminated by removing the solids that accumulated over the winter months before they caused an upset in the tank.

The sulfides averaged, in Table 3, were 10.2 ppm over the year in the rock column, which is a threefold increase in magnitude over the 2.8 ppm average of the contact tank. The highest concentration of sulfides coming from the rock column was 17 ppm, which presented an odor problem. In Figure 4, the variations in the sulfide concentrations are shown.

Depth of Rock

An attempt was made to improve the performance of the rock column by increasing the depth of media. During the fall a small laboratory rock column of 3 inch diameter was added in series and the flow rate adjusted so that upflow velocity would be equal to that in the larger unit. The purpose of this study was to see if the doubling of the rock depth to 8' was beneficial and justifiable. There was a corresponding improvement in removal of COD; however, the suspended solids were consistently greater in the effluent. It was decided that this additional rock depth was not justifiable. This small column gave the first suspicion that unloading was likely to occur in the secondary unit.

Conclusions

1. Analysis of laboratory and pilot plant data shows that the anaerobic contact process provides substantial removal of organic matter.
2. For the year's operation, removal of 83 percent suspended solids and 62 percent COD were obtained in the anaerobic sludge contact tank with an inoffensive sulfides concentration of 2.8 ppm in the effluent.

3. In the sludge contact unit, gas production was small with little or no methane developed. There was an absence of a scum formation or spring upset in this unit.

4. The upflow of sewage forms channels through the sludge. Sudden large increases in flow wash some solids out of the blanket of sludge; however, sustained increased upflows of 15 ft/day or less give satisfactory sludge detention.

5. Thermal-density differences greatly affect detention time. If conditions warrant, the tanks should be placed below ground to minimize unfavorable liquid density differences.

6. The expensive conical shape of the pilot plant sludge contact tank has no advantage in comparison with a cylindrical shape in flow distribution. Multi-outlets were found to have a beneficial effect by reducing the "dead areas" caused by the single outlet in the pilot plant sludge contact tank.

7. The anaerobic upflow rock column has removed 44 percent of suspended solids and 10 percent COD; discharging an odorous effluent with 10.2 ppm of sulfide for the year's operation. Odor would make the use of the rock column unit objectionable in the immediate vicinity of a subdivision. However, COD removal efficiency would be increased to 20 percent by a yearly spring cleaning.

8. Doubling the depth of media in the rock column is not justified by a corresponding improvement in removal efficiencies.

Summary

An anaerobic process for suburban sewage treatment using an upflow sludge contact unit and an upflow rock column unit has been tested in a pilot plant installation. The installation had a total liquid capacity of 222 cu. ft. and was operated with a 24 hour detention at a constant flow. Domestic sewage with an average strength of 695 ppm of COD and 429 ppm of suspended solids was used as a feed.

The combined units removed 91 percent of the suspended solids and 66 percent of the COD. The final effluent contained an average strength of 237 ppm of COD and 41 ppm of suspended solids. The anaerobic sludge contact unit did the majority of the work in producing an effluent with an average strength of 72 ppm of suspended solids and 263 ppm of COD. A linear relationship existed between the BOD and COD. There was an absence of a scum formation, offensive odors, or spring upset in the sludge contact unit.

The simplicity of design and absence of moving parts give promise of low initial and maintenance costs. The operational data show an efficient process for suburban sewage treatment.

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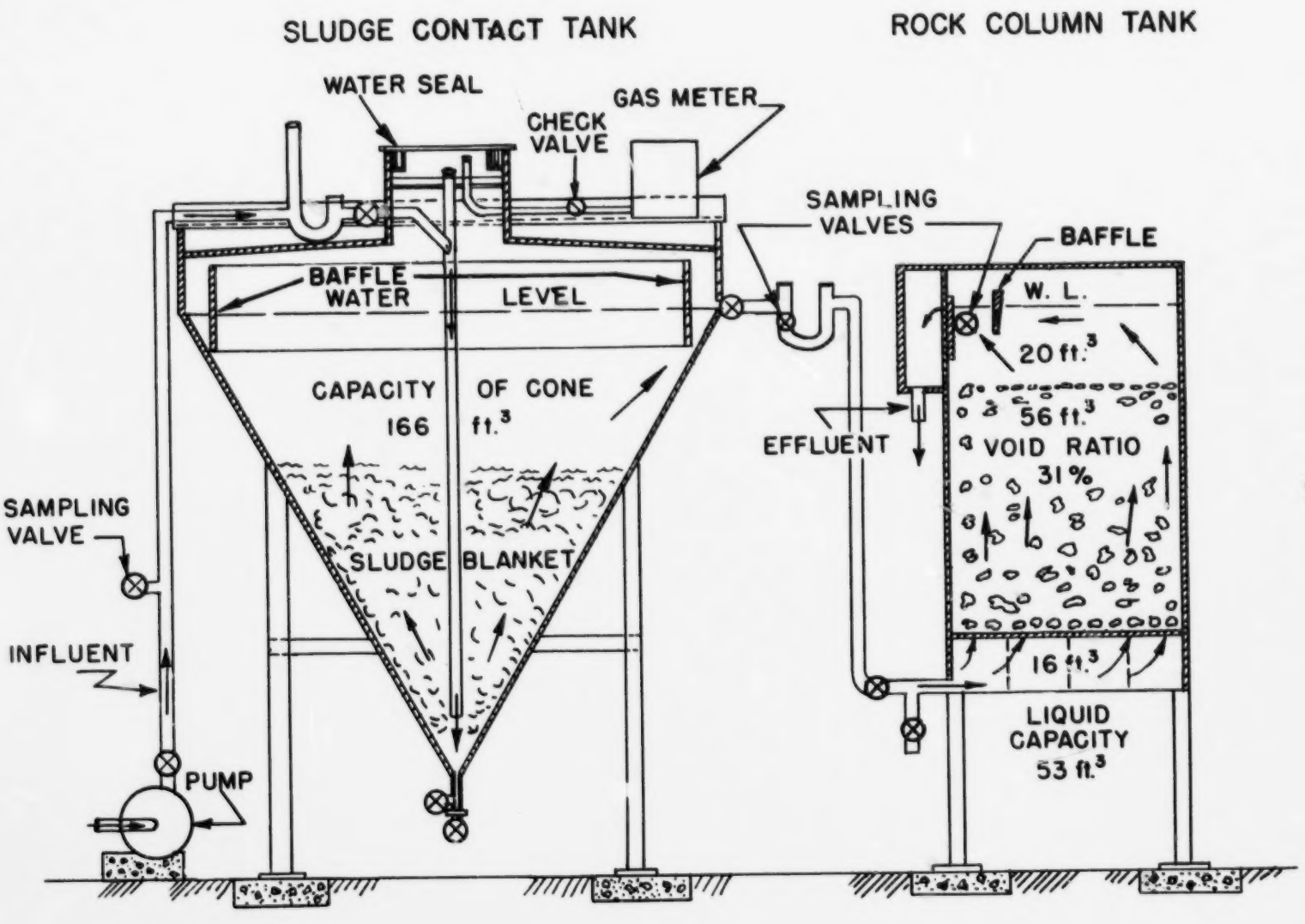
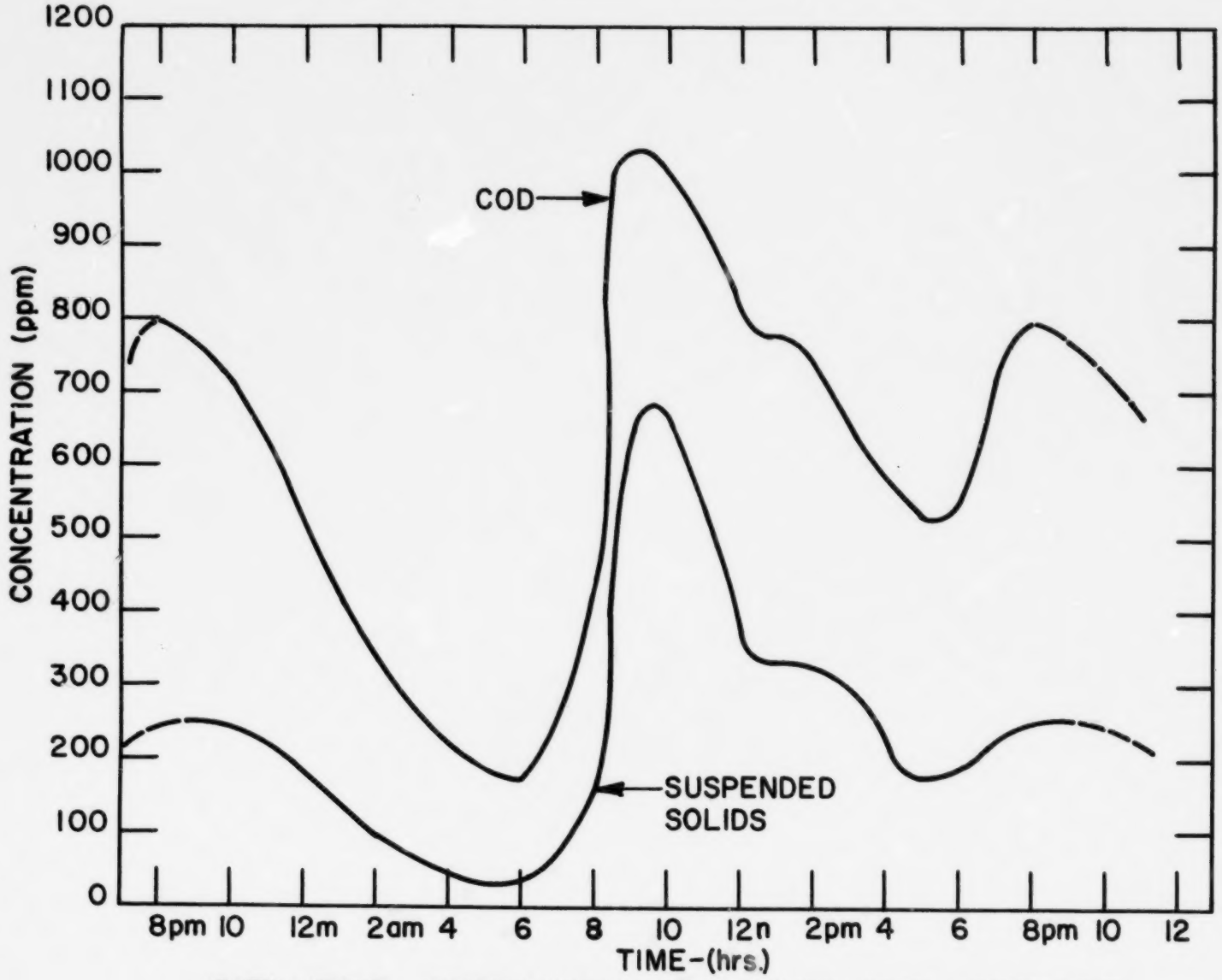


CROSS SECTION OF LOVELAND PILOT PLANT

FIGURE 1



INFLUENT STRENGTH OF LOVELAND SEWAGE

FIGURE 2

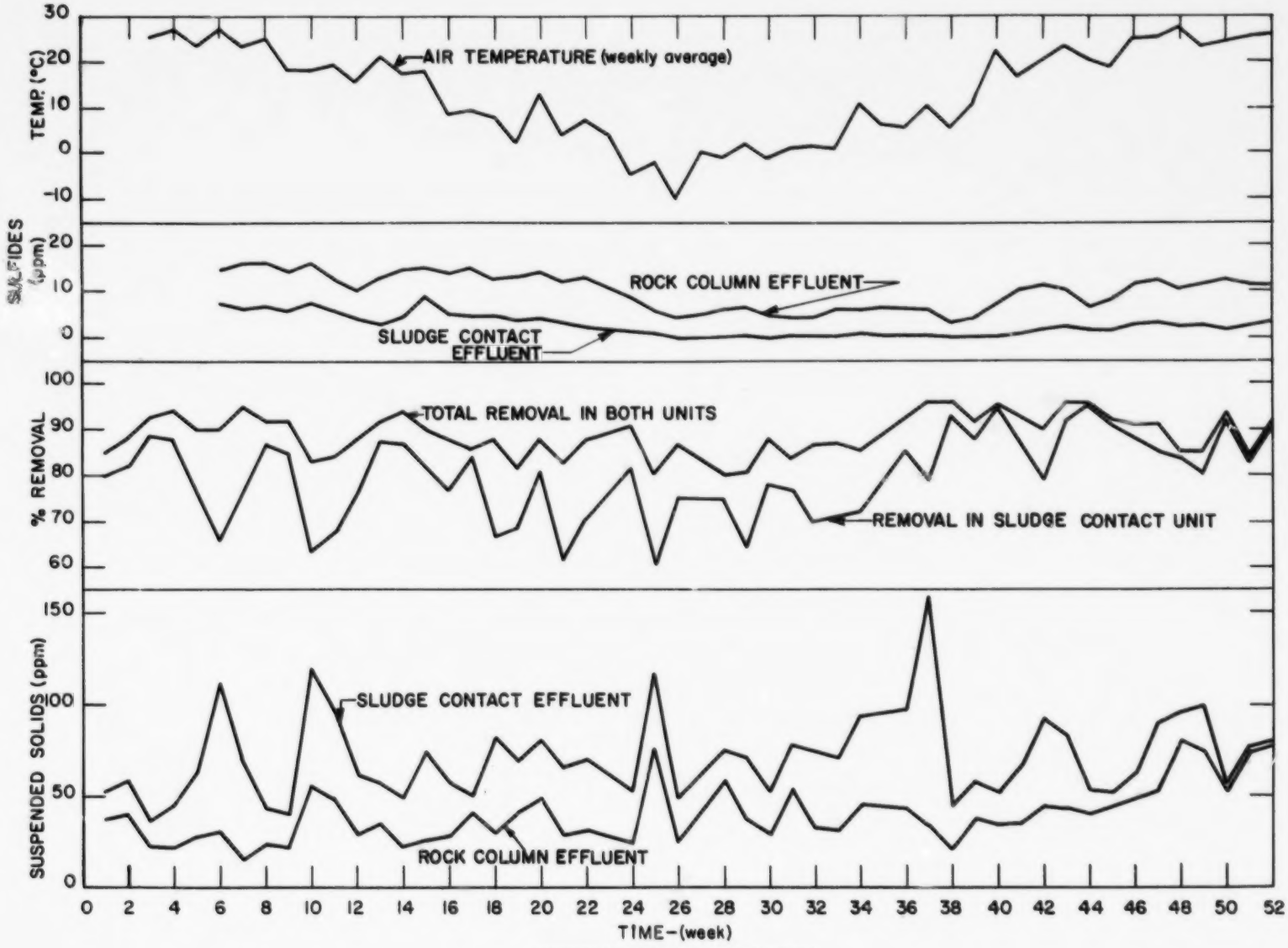
TABULATION OF DATA

Weekly Averages

Weeks	Suspended Solids (ppm) Inf.	Pri Eff	Sec Eff	COD (ppm) Inf.	Pri Eff	Sec Eff	Sulfide (ppm) Inf.	Pri Eff	Sec Eff	Air Temp (°C)
1	260	53	38	564	309	287				
2	332	59	40	683	336	298				
3	328	37	22	725	317	288				25.6
4	377	46	22	854	364	301				27.8
5	275	63	28	619	307	265				23.5
6	327	112	31	655	413	316		7.6	15.0	27.4
7	298	71	16	671	267	244		6.5	16.3	23.3
8	332	44	25	678	286	276		7.0	16.5	25.6
9	278	41	23	672	272	252		6.0	14.6	18.1
10	332	120	56	747	372	318		7.5	16.2	19.0
11	303	98	49	685	335	289		6.0	13.0	19.8
12	256	62	30	662	339	283	1.2	4.3	10.0	15.9
13	480	58	36	717	321	286	0.1	3.0	13.0	21.4
14	392	50	23	727	334	295	1.0	4.4	15.0	17.1
15	424	75	42	801	365	309	2.3	9.6	15.4	18.5
16	253	59	29	—	363	315	3.0	5.2	14.0	8.5
17	313	50	43	—	403	343	5.5	5.0	15.5	9.6
18	249	83	31	—	405	304	2.2	5.0	12.8	8.4
19	229	70	42	—	345	276	2.0	4.0	13.5	1.8
20	416	81	50	1109	347	289	4.0	4.4	14.4	13.4
21	168	95	43	618	329	233	0.8	3.2	12.2	3.7
22	242	71	32	829	315	240	0.5	2.7	13.2	7.1
23	—	—	—	—	—	—	—	—	—	4.9
24	286	54	26	598	348	255	0.0	1.6	9.0	-4.6
25	226	85	50	698	367	258	0.0	0.8	6.2	-1.9
26	199	50	25	584	260	229	0.0	0.0	4.3	-9.7
27	—	—	—	—	—	—	0.0	0.0	5.2	0.5
28	298	75	60	537	241	208	0.0	0.1	6.4	-0.4
29	208	73	39	495	212	166	0.0	0.2	7.0	2.6
30	248	54	30	398	162	130	0.0	0.0	4.8	-0.3
31	348	79	55	675	251	162	0.0	0.4	4.7	1.5
32	257	76	33	505	224	141	0.0	0.5	4.7	2.5
33	248	72	32	449	185	127	0.0	0.4	6.5	1.7
34	—	94	47	—	244	181	0.0	1.0	6.2	11.7
35	—	—	—	—	—	—	0.0	0.4	6.7	6.8
36	671	98	44	754	278	209	0.1	0.7	6.2	5.7
37	764	159	33	567	193	134	0.0	0.5	6.2	10.3
38	605	45	22	384	115	91	0.0	0.0	3.3	5.7
39	498	58	39	588	171	145	0.0	0.1	4.5	11.7
40	932	52	35	727	153	175	0.0	0.1	7.9	22.2
41	532	68	36	775	172	185	0.0	1.0	10.6	17.3
42	436	93	45	845	232	251	0.0	2.0	11.3	20.1
43	1083	84	43	1194	241	279	0.1	2.6	10.2	23.7
44	1004	54	40	704	134	187	0.1	1.3	7.1	20.3
45	576	52	44	611	131	174	0.0	1.7	8.1	19.0
46	546	63	49	609	163	207	0.0	3.0	11.8	25.4
47	585	90	53	833	183	262	0.1	3.2	12.2	25.8
48	576	92	86	904	244	332	0.1	2.4	10.6	27.9
49	492	100	73	726	158	243	0.1	2.7	11.8	23.7
50	812	63	56	745	130	191	0.1	1.9	12.3	24.2
51	460	78	74	749	157	230	0.2	2.9	11.8	25.8
52	835	79	85	929	163	194	0.4	3.9	11.6	26.7

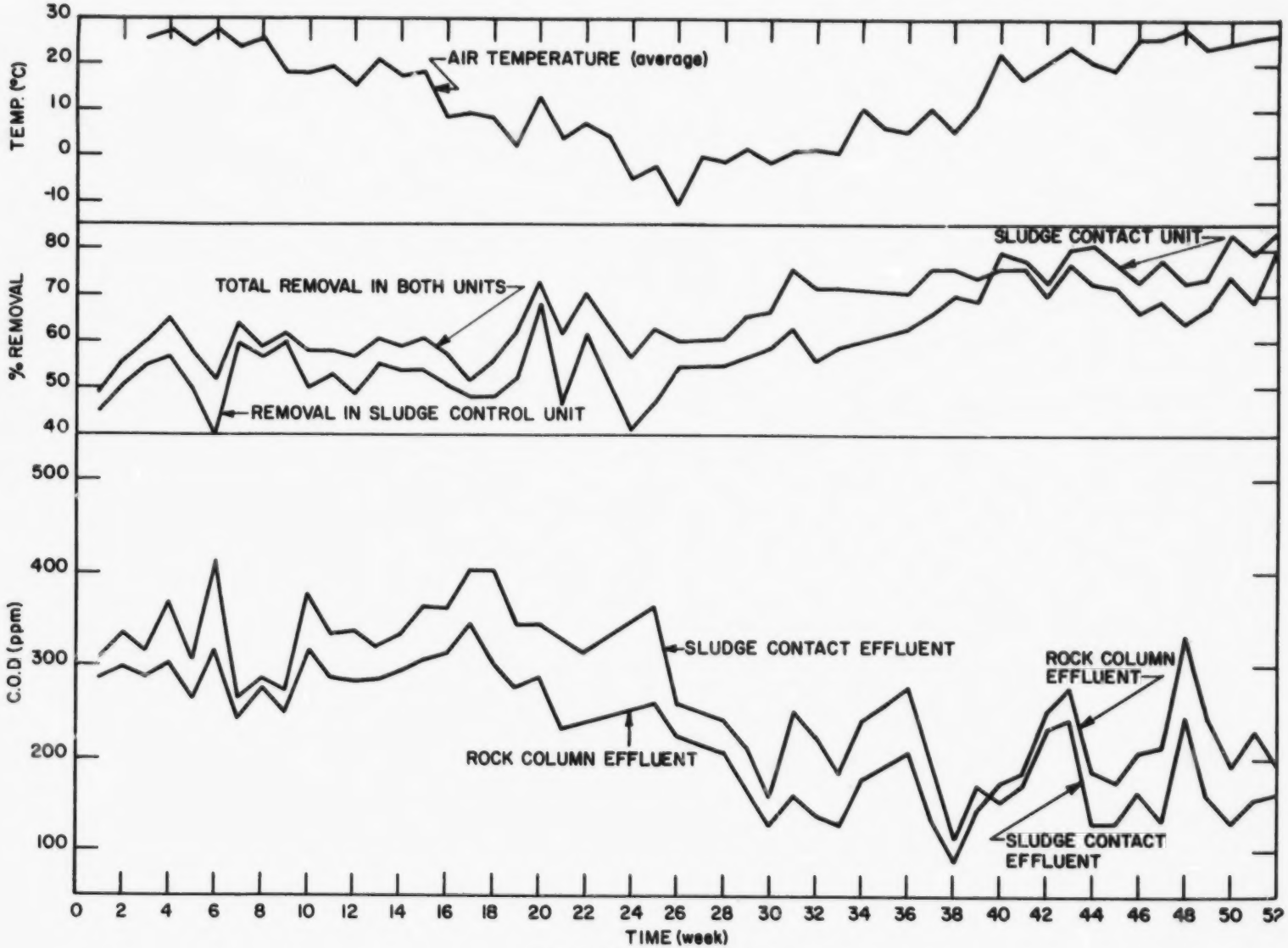
TABULATION OF OPERATIONAL DATA

FIGURE 3



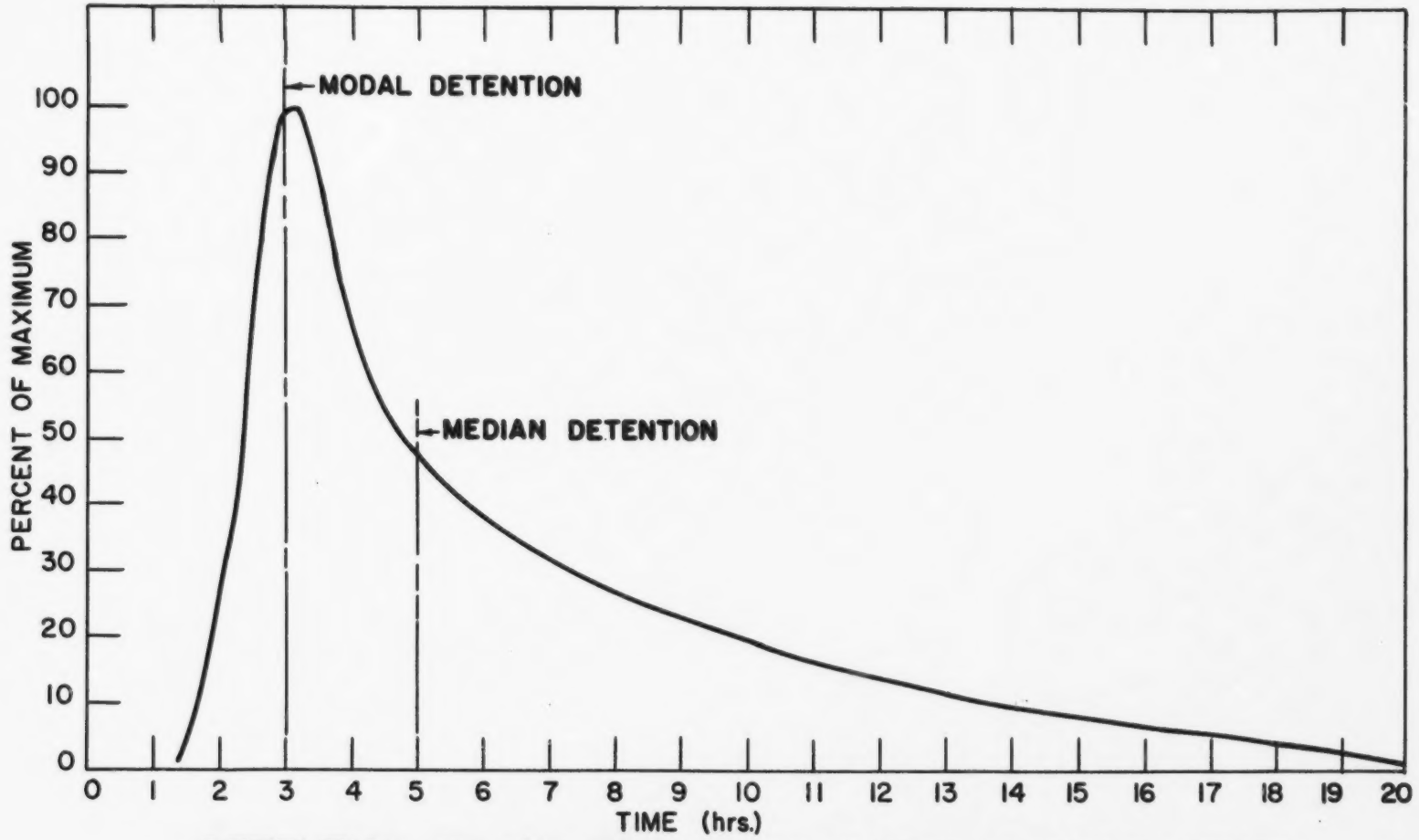
OPERATIONAL GRAPHS

FIGURE 4



OPERATIONAL GRAPHS

FIGURE 5



DETENTION OF DYE TRACER IN SLUDGE CONTACT TANK

FIGURE 6